Development of a fast and highly efficient gas ionization chamber for patient imaging and dosimetry in radiation therapy

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The tasks of phase 1 were: a) determination of kind of septal plate metallic material and optimization of its thickness, b) preparation work for building the prototype detector, such as choice of insulator material and layout of the electrical circuits, and c) final determination of the kind of septa plate material and its thickness.

Task a): The calculations were performed with two Monte Carlo radiation transport packages EGS4/BEAM and MCNP4C. Two types of radiation detectors were successfully implemented in EGS4/BEAM. The first detector was a conventional, arc-shaped xenon detector used in earlier generations of CT scanners. The detector consists of 738 detector channels every single of which thin tungsten septal plates divide into two gas cavities. This detector is described in more detail in the proposal. Other detectors were the prototype detectors described under task b). These detectors were also modelled in MCNP4C.

The measured detector response for the xenon arc detector could be successfully reproduced with the Monte Carlo calculations. This confirmed the correctness of the model for the transport of the radiation through the geometry. The results show further, that the efficiency of an array structure consisting of high-density converter material interspersed with gas cavities as the active medium surpasses the efficiency of other detector technologies by far. Comparisons using different types of metals for the septal plates have yet to be done.

Task b): Several prototype detectors were successfully constructed. The first prototype is shown in Fig. 1 and consists of 3 active and two guarded cells. The triangular-shaped upper part made of aluminum served as the converter structure for the conversion of high-energetic photons into electrons. The converter structure is not permanently attached to the epoxy base but can easily be replaced by similar structures made of different metals. In addition to the aluminum, structures made of copper, lead and brass were made. The second protoptype consists of 5 active and two guarded cells. The geometry is simpler than for the first prototype (indicated in Fig. 2) and allowed a better quantification of the volume of the air cavities. The cells are defined by seven 1.02 mm wide rectangular notches in a block of aluminum. The spacing of the cells is 1.45 mm. To guarantee a high number of interactions with the incident beam the length of the Al electrodes in beam direction is 42 mm. The aluminum block rests on an epoxy base. The epoxy also holds 5 1.27 mm thick steel shims which serve as the collecting electrodes. A voltage of 110 V was put across the Al structure and the steel shims. Air at atmospheric pressure is used as the gas. With this prototype some experiments using

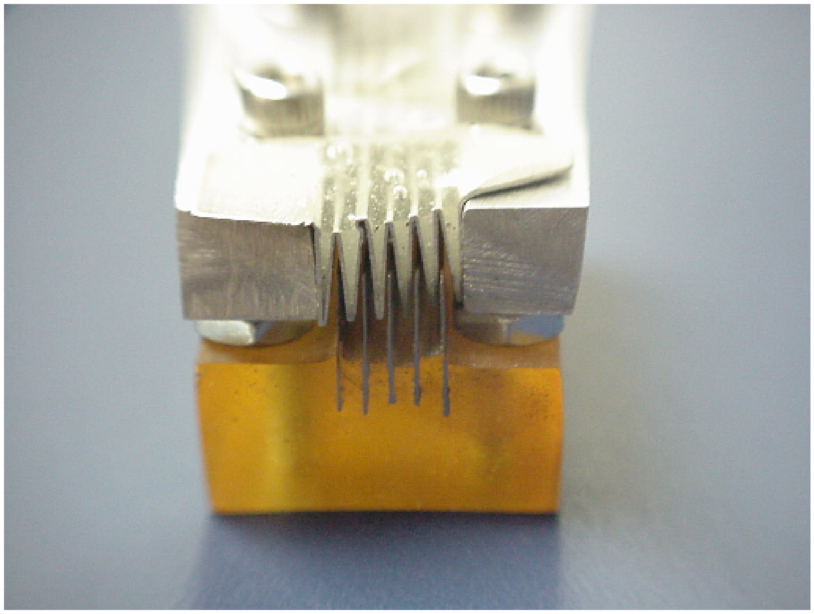

Figure 1: *First prototype detector consisting of three active cells in the center and two guarded cells at the sides. The converter structure is aluminum, the collecting electrodes are made of brass and the base is epoxy. The distance between the brass shims is about 1.2 mm. The detector is irradiated from the front.*

4 MV radiation were performed. The results of one of these measurements is shown in Fig. 3. The results indicate, that the signal increases by misaligning the plates of the converter structure with respect to the incident photons. This effect is even more pronounced by using tungsten as the converter material. The converter structure of the third prototype currently under construction is a two-dimensional grid of 16 brass tubes.

A new calculational method of supporting design considerations was developed. To study the importance of the signal contribution from different converter structures, spatial maps of the origin of the absorbed energy (so-called "importance maps") were calculated. One example of such a map is shown in Figure 2. They provide information to optimize dimensions and choice of materials at once.

A first attempt to manufacture the proposed design described in the proposal failed. The reason for this was the bad quality of tungsten which prevented a successful carving of the structures with the wire EDM technology. In phase 2 of the project we will pursue the manufacturing of this design using a higher quality of tungsten.

All in all, the accomplished tasks described under b) were successful, although we suffered from a delay in the delivery of some metallic materials as well as electronic components. Some preliminary experiments were performed with self-made read-out electronics. The collected charge in the air cavities was about five times larger than in a conventional ionization chamber. However, the results do not yet allow to draw definitive conclusions.

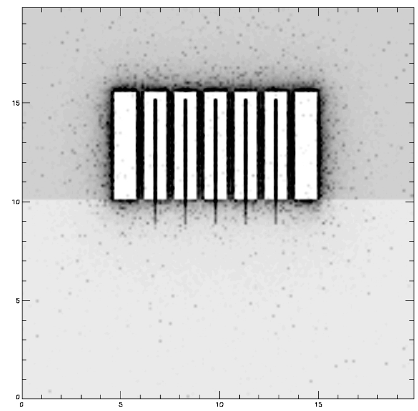

Figure 2: *Map of the relative contribution (importance) to the absorbed energy in the active medium of the second prototype detector. The upper part is the converter structure made of aluminum, the bottom part the epoxy base. The detector is irradiated in direction into the plane of display. In each of the air cavities the ionization charges are collected by thin steel electrodes. The absorbed energy in the air cavities was mapped back to the location of the first interaction of the photon. Locations with a high contribution appear darker. The importance distribution is shown on top of a gray scale image of the prototype detector. In this case the contributions from each material to the absorbed energy in air was: aluminum 68%, steel shims 18%, epoxy 13%, and air 1%.*

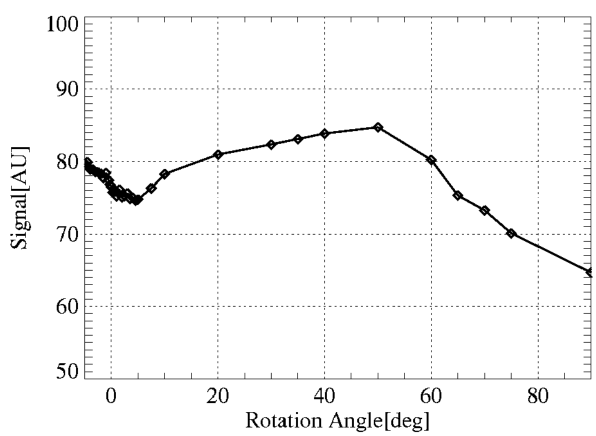

Figure 3: *Measured signal in the central cavity of the second prototype detector as a function of its orientation angle with respect to the incident photon beam axis. "0" is a perfect alignment with the beam axis.*

Task c): The calculations together with the performed measurements did not yet allow to draw conclusions about the ideal plate thickness and plate separation. The optimal choice of the plate thickness is a trade-off between resolution and efficiency. In general, thicker plates are more efficient, but decrease the amount of charge collected due to a smaller gas cavity collection volume and decrease the resolution due to a larger cell size.

Conclusion

In conclusion and in relation to the goals of phase 1, the accomplished tasks described under b) were very successful, whereas task a) together with task c) need some additional work which will be performed in the beginning of phase 2 of the project.

Publications

The work done so far resulted in the submission of a paper manuscript to Medical Physics, and two abstracts one to the ANS Summer Meeting in Milwaukee, WI [1], and one to the IEEE-Medical Imaging Conference, to be held in San Diego, CA in November 2001.

References

[1] H. Keller, M. Glass, R. Hinderer, K. Ruchala, R. Jeraj, G. Olivera, T. R. Mackie, and M. L. Corradini, "Monte Carlo characterization of a highly efficient photon detector," Transactions of the American Nuclear Society, Vol. 84, 2001 Annual Meeting, Milwaukee, WI, June 17–21, 2001, TANSAO **84**, 83–84 (2001).